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Cost Benefit Analysis of Composting and Anaerobic Digestion in a Community: A Review

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Currently, population and urbanisation are rapidly growing which causes a tremendous amount of municipal solid waste (MSW) being generated. The MSW management in Malaysia can be considered relatively poor and disorganised. The most preferred MSW disposal method in Malaysia is through landfilling. To address this and to respond to increasing global environmental concerns, composting and anaerobic digestion have been hailed as an environmentally and economically friendly alternative besides landfilling. By capturing the organic materials from MSW and putting it to a more beneficial use as feedstock for composting and anaerobic digestion sounds very ideal. Focusing on the waste landfilling prevention for a small community, this paper discusses on whether composting or anaerobic digestion might be a feasible alternative to landfilling. Both solutions differ in various aspects. The purpose of this study is to know whether composting or anaerobic digestion is more beneficial by performing cost benefit analysis on both situations. In this study we estimated the cost benefit analysis of three different scenarios. First scenario is the baseline for the current practice of solid waste management where the wastes are dumped to landfill. Second scenario is the installation of composting plant and the third scenario will be estimated on the installation of anaerobic digester.

1. Introduction

Compared to a few years back, the population and urbanisation of the world are rapidly growing. The economics value and the standard of living of the community are rising. In this global waste market, municipal solid waste (MSW), which refers to the waste generated by residential, commercial and institutional activities, occupies about half of that market. As the world is moving toward its urban future, the amount of MSW, one of the most important by-products of an urban lifestyle, is growing even faster than the rate of urbanisation. Ten years ago there were 2.9 billion urban residents who generated about 0.64 kg/person-d of MSW. This report estimates that today these amounts have increased to about 3 billion residents generating 1.2 kg/person-d. By 2025 this will likely increase to 4.3 billion urban residents, generating about 1.42 kg/person-d of municipal solid waste (Hoornweg and Bhada-Tat, 2012). More than half of the MSW in Malaysia is made out of organic solid waste and the MSW generation is expected to exceed 9 million t per yr by 2020 based on the current MSW production rate of 0.5 - 0.8 kg/person-d (Saeed et al., 2009). Food waste is the main constituent organic matter from waste produced in community, with approximately 30.6 % (Kalantarifad and Yang, 2011). With the increasing MSW generation, this leads to severe problems in terms of limited land available for waste disposal in all countries. In Malaysia, landfilling is the dominant disposal method for 98 % of the MSW generated. The existing disposal sites in Malaysia mostly are not properly engineered and managed, pollutant that are released or discharged from the disposal sites eventually caused direct and indirect impact to human's life (Shahir et al., 2010). The Malaysia government was reported to spend about USD 300 M in year 2014 alone for the operating cost for MSW management (Bong et al., 2016). Besides landfilling to dispose MSW, composting on the other hand is considered to be a more environmentally friendly waste management option. Stabilisation of organic wastes by composting is highly desirable as composting eliminates odour, increases

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nutrient contents, and prevents the organic wastes from becoming phytotoxic when incorporated into the soil (Kuo et al., 2004).

The end use of compost is primarily for nutrient recycling and promoting plant growth. The feasibility of composting depends very much on the quality and consistency of compost produced as they affect compost marketability and its end use. Stabilisation of organic wastes is often done with composting, which is a microbiologically mediated process. Compost contains many essential nutrients and improves soil physical and chemical properties. Compost, if properly prepared, is beneficial to the productivity of field and container crops. A study showed that the application of olive mill based compost was capable to improve soil quality as reflected by the studied chemical parameters, especially in terms of the more resistant pool of organic matter, which is the key for sustainable agricultural management (Aranda et al., 2015). However, composting has potential negative impacts to the environmental due to the consumption of fossil fuel during transportation and processing equipment, as well as fugitive emission of greenhouse gases (GHG) (Boldrin et al., 2009). The application of immature compost can also lead to severe health issues and phytotoxicity to plants. The continuing decomposition process present in soil can induce the anaerobic conditions as the oxygen present in soil pores are being utilised by the microbial biomass. This in turn can deprive plant roots of oxygen and lead to the generation of H_2S and NO_2^-. Depending on the scale and operating mode, composting facilities also varied in capital, operation and maintenance cost.

Other than composting, one of the ways to treat organic waste biologically is anaerobic digestion, where the end products are the digestate, which can be used as compost and the biogas, which can be used to generate electricity and heat. Anaerobic digestion plays an important role in sustainable development by producing biogas as renewable energy. Energy is a necessity in daily life so the demand for electricity and heat increases from time to time. Mostly, energy is generated from fossil fuels. Fossil fuels are one of the non-renewable energy. This could give a bad impact to our environment. Alternatively, biogas which is a renewable energy can be produced from organic solid waste. Biogas is a mix of mainly methane, carbon dioxide with small quantities of other gases which can be converted to generate heat and electricity. Biogas digester designs for community level in rural areas usually are in small scale. The benefits of anaerobic digestion have been widely published. Both life cycle assessment and cost benefit analysis have found anaerobic digestion to be the best method of dealing with household waste (Edelmann et al., 2005).

So there are three options or scenarios that are considered in this study for the disposal or treatment of the organic municipal solid waste. The purpose of this study is to analyse the cost benefit of the three different scenarios, namely scenario 1 (landfill (LF)), scenario 2 (composting plant (CP)) and scenario 3 (anaerobic digestion plant (ADP)). The results from the assessments will be able to provide better insights and thus facilitate better decision making for policy makers and investors towards implementation at sub-urban community economically.

2. Scenario Analysis

2.1 Scenario 1: Landfilling (baseline)

In scenario 1, all the MSW generated are sent to landfill for disposal. For this scenario, current practice of solid waste management for most people is reflected. All the waste is collected approximately three times a week by the party responsible and are sent to landfill for disposal. The landfill site is not equipped with methane gas recovery and is estimated to receive 73 t/y organic waste from FTA based on a generation rate of 0.2 t/d. Figure 1 showed the overall process flow of waste management in scenario 1.

Figure 1: Scenario 1 - Flow process for Landfilling

2.2 Scenario 2: Composting Plant (CP)

Scenario 2 implements composting in the small community within the village to manage the organic waste. Composting is selected in this study because it is easier to manage and require less complicated technology. It is a biological treatment in which the organic wastes produced can be treated and transformed into a drier, more uniform and biologically stable product with many uses other than just land application (Sikora, 1998).

For this scenario, it is assumed that residence had already implemented waste segregation and 100 % of food waste are collected and sent to the composting plant located nearby the residency. The composting plant is targeted to be off site composters where food wastes are delivered to a small-scale site for processing. Before composting, the food waste was screened and shredded. Composting method was applied where the food waste was mixed with seed compost which was rich in effective microorganism (EM). Finished compost can be a source of income to the community groups. Community groups need to be responsible for the labour tasks. In other cases, worker-owned cooperatives may be formed where everyone is paid. Figure 2 illustrated the waste flow in scenario 2.
The microorganisms in the compost pile function best when the compost materials are about as moist as a wrung-out sponge, and are provided with many air passages. However, the excessive aeration might lead to the release of more GHG and sometime it slow down the degradation process. However, as an aerobic process, the excessive of moist can lead to the block of the air passage which further leads to the anaerobic condition of the compost pile. This not only causes the more release of GHG, but also slows down the process by inactivating some microbial activities. The proper management of the process is essential to ensure the final quality of the compost. Figure 3 shows the inputs and outputs in a composting plant.

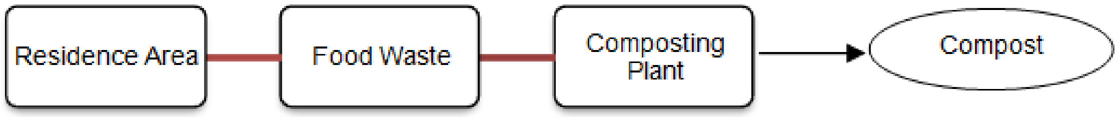

Figure 2: Scenario 2 - Flow process of Composting Plant

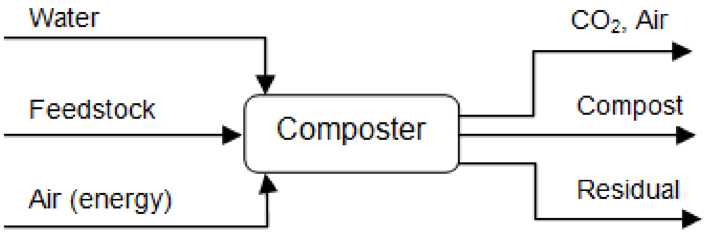

Figure 3: Composting Inputs and Outputs

2.3 Scenario 3: Anaerobic Digestion Plant (ADP)

Scenario 3, implement anaerobic digestion process to treat the waste generated in the community to produce biogas. Anaerobic digesters are fully enclosed structures, such as tanks or other sealed containers, in which the entire digestion process occurs. Anaerobic digestion produces biogas (consisting primarily of methane and carbon dioxide) and digestate. Digestate is the solid and/or liquid residual material remaining after organic material has been digested. Biogas can be used to generate electricity and heat, the digestate produced can be used as compost. Energy input is required for feedstock preparation, heating the digester tank, and pumping. For this scenario, apply the same assumption that residence had already implemented waste segregation and are collected and sent to the AD plant. The digestate produced can be further process as fertiliser and sold as a source of income to the community groups and the biogas produced will be sold or used for the community itself. Gas produced can be supplied to community as cooking gas. Figure 4 and 5 illustrated the waste flow in scenario 3 and its inputs and outputs.

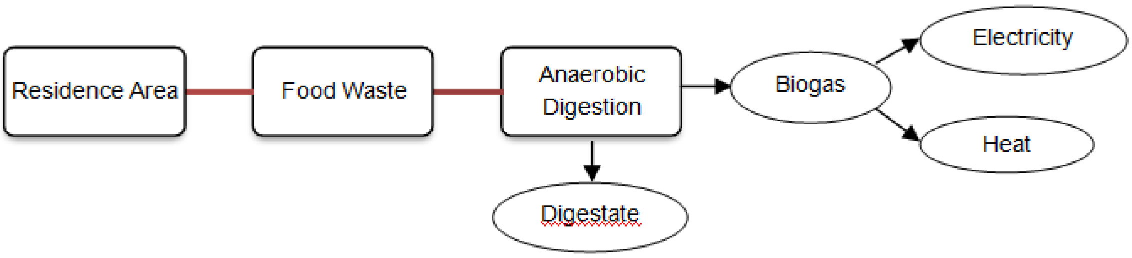

Figure 4: Scenario 3 - Flow process of Anaerobic Digestion Plant (ADP)

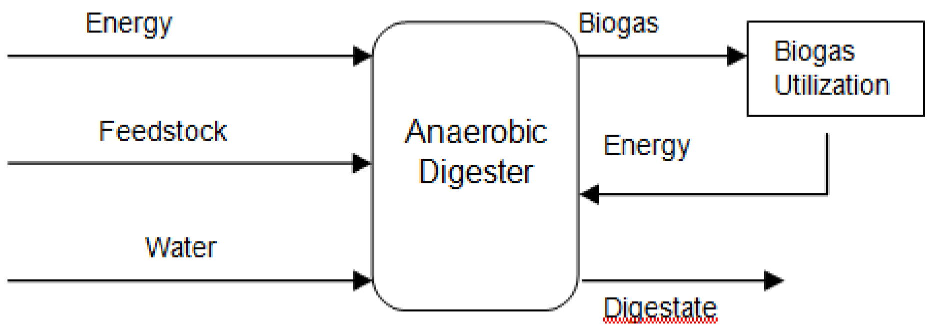

Figure 5: Anaerobic Digestions Inputs and Outputs

2.4 Case Studies

In the existing literature by Bong et al, (2016), the community selected as reference is located in Felda Taib Andak (FTA), Kulaijaya, Johor. The community comprises of approximately 600 households and has a population equivalent of 3,000 (5 person/ household) with the capacity to generate 72 t of MSW per mth considering 0.8 kg of waste per person is generated. Approximately from the total 72 t of MSW, about 30 t of it is food waste. The large quantities of readily degradable organic waste are a potential feedstock for composting to produce compost or anaerobic digestion to produce biogas and digestate. In this study, instead of total 600 households in FTA, only 50 households will be involved. The main goals for this analysis is to reduce the amount of waste dispose to the landfill thus reducing the disposal cost and working on the possibility of zero waste community besides hoping to engage youth or community leaders in the art and science of composting and encourage community to produce a marketable, saleable product using the readily source available.

2.5 Limitations

This study targeted on small community of approximately 50 households within FTA with food waste generation of approximately 1 t per week. However, if there is the need to grow, the feedstock of both the facilities are readily available. In the meantime, only 50 households will be considered to see the potential. Scenario 1 serves as the baseline case which is the major MSW management practice, where all the collected waste is sent to the landfill. The composting plant in small community in FTA is name as scenario 2 and an anaerobic digestion plant name as scenario 3.

3. Cost and Benefit Analysis (CBA)

The CBA takes into account of the economical assessment for all three scenarios which is important as it can provide information on the setting up cost and potential revenue generation which serve as reference for local authorities or investors of interest.

The cost for installation of composting facilities is not high compared to anaerobic digester, it will only involve the construction of compost bin. Capital costs for AD are higher due to equipment construction, which includes: equipment to weigh and receive feedstock, feedstock pre-processing equipment, digester, energy generation equipment, and hydrogen sulphide clean-up equipment. Several studies were reviewed to determine approximate installed costs for food-waste-based digesters.

The operation cost is not considered since all operating will be manually handled by community groups.

It is not possible to determine the actual wastes delivered to a facility. For the purposes of this study, total food waste and potential collection rates were estimated. Food wastes are estimated to contain 30 % of solid portion. It is assumed that methane content in total biogas production is around 60 % and 10 % of biogas is used as captive energy to operate the plant and associated buildings. The rest of the biogas produced can be used by the community as cooking gas or being sold to generate income. The final product, digestate, will be composted to produce fertiliser. Similar to the Scenario 2, the fertiliser produced can be sold as a source of income for the community. For Scenario 2, it is assumed that for every 1 t of food waste, it produced 0.2 t of finished and mature compost. In which, each year, 14.6 t of mature compost will be produced from 50 households with the degradation of total 73 t of organic waste per year. Tipping fees for scenario 1 and scenario 2 are not considered since separation and delivery of waste to the facilities are done by the residence themselves. Table below shows the parameters for the solid waste management in Felda Taib Andak.

Table 1: Parameter for the solid waste management in Felda Taib Andak

Parameter	Base case	Scenario 1	Scenario 2	Remark
Waste generation (t/d)	0.2	0.2	0.2	0.8 kg/person of waste for 50 household
Average distance from transfer station to hub (km)	N/A	7	7	
Tipping fee/waste collection fee (MYR/y)	80	N/A	N/A	80 MYR/household/y; tipping fee for 50 households were considered
Capital Cost (MYR)	N/A	1,802	19,323	Capital cost was normalised for 20 y
Operation and Maintenance Costs (MYR)	N/A	1,000	1,000	For transportation vehicles, site, miscellaneous.
Fertiliser price (MYR/t)		1,000		
Electricity price (MYR/kwh)		1.09		
Biogas price(MYR/m^3)		18.5		
Electricity production from biogas (kWh/m^3)		N/A	2.1	
Heat production from biogas (kWh/m^3)		N/A	2.5	
Biogas production (m^3/t MSW)		N/A	203.6	
fertiliser production (t/y)		18	1.07	

4. Results and Discussions

Anaerobic digestion is an expensive process to complete compared to composting. It requires continual introduction of large quantities of feedstock in order for the process to work efficiently. This is one of the reasons that it generates large quantities of methane gas as the food waste decomposes. That methane gas is not only highly combustible but also one of the most potent GHG on the planet. AD creates a sludge-like material that is even more difficult to break down called digestate. This requires time and considerable amounts of energy to accomplish. It can take up to a year before an anaerobic composter can fully break down the raw material into viable compost. The private benefits of anaerobic digestion accrue from the generation of electricity using methane as a source of power and the sale of compost, another waste product from the anaerobic digestion process. AD is more technical complex compared to composting as it requires delicate control to ensure desired output. Process failure can be occurred with the overloading of feedstock and the undesirable process configuration. As a process that produces around 60 % of methane gas, the easily flammable character of CH_4 can lead to explosion if the plant is not handling properly.

Compared to AD, the process of composting is very simple; the by-products are simply heat, water, and carbon dioxide (CO_2). While CO_2 is a greenhouse gas, it is at least 1/20th as potent as methane. To minimise the impact on the environment, the CO_2 gas can be safely collected via a gas collection system that will prevent the gas from seeping out into the environment. Although there is some potential of CH_4 and N_2O generation, the proper management of the process and the application of some amendments can minimise the production of this gases. Naturally, one of the most important benefits of aerobic compositing is that the heat which is produced during the decomposition process is great enough that it kills harmful bacteria and pathogens within the pile.

5. Conclusion

The cost benefit analysis between landfilling, composting, and AD for organic material of MSW for a case study in FTA residence was performed in this study. The finding suggested that composting is the most economical profitable and environmental feasibility alternative as compared to AD. Composting options have moderate environmental impacts among the options compared. Biogas production has the lowest environmental impacts. The waste transportation in each scenario does not have significant impact on greenhouse effect. Composting in a centralised plant has the highest potential for success in handling organic material of MSW in a community in Malaysia. Both uses of either composting or anaerobic digestion processes can play a significant role in achieving Malaysia's goals for reducing GHG emissions and reducing the volume of waste deposited in landfills. However, AD facilities bring significant benefits to the society. If the goal of a community is to be self-sufficient, produce fertiliser and energy and avoid pollution, a small AD unit can be very profitable. To be able to implement this option, further detailed studies are recommended. It should be noted that the supports from the community management and the local government would be the keys to the success. In a nutshell, this study showcased a community composting and community AD project as a viable way to reduce the amount of organic waste to the landfill and producing value-added products such as compost, fertiliser and biogas. In terms of social involvement, the project will benefit the local residence of FTA by transferring the technology and knowledge to the community where the good practice of 3R (reduce, reuse and recycling) is introduced.

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